AMEC Design Calculation or Analysis Cover Sheet

Project: PSEG RAI Support	Calc/Analysis No. 0360-RAI-061-9 (Computer Serial #: FCLP006)	AMEC Project No. 6468-11-0360
Title: Smooth Vertical GMRS for PSEG Site Based on CEUS SSC	Client Contract Purchase Order Discipline Seismology	Sheet No. 1 of 12
Computer Program N/A	Version / Release No. N/A	
Purpose and Objective Calculate smooth vertical GMRS for the PSEG Site by applying V/H ratios to the horizontal GMRS from calculation 0360-RAI-061-8.	Quality Assurance Conditions (e.g. safety classification) Safety-related	

Summary of Conclusion:

Smooth vertical GMRS for the PSEG Site was calculated by applying V/H ratios to the horizontal GMRS. Figure 3 is a plot of the final vertical GMRS for the PSEG Site. Table 1 shows numerical values for the final vertical GMRS spectrum for the PSEG Site.

Revision Log

Rev. No.	Revision Description
0	Initial Issue

Sign Off

Rev. No.	Originator (Print) Sign / Date	Verification Method	Verifier (Print) Sign / Date	Technical Lead (Print) Sign / Date
0	Osman El Menchawi 11/28/12	Technical Review	Allison Shumway 11/28/12	J. Allan Tice 11/29/12

Additional Reviewer (Print)	Signature	Date

AMEC DESIGN VERIFICATION CHECKLIST

(Excerpted from ANSI N.45.11 [1974 Edition] and ASME NQA-1 [1994 Edition]

Project PSEG RAI Support	AMEC Project No. 6468-11-0360	Calculation No. 0360-RAI-061-9	Rev. No. 0

Yes	No	N/A	Design Verification Element Note: Any items checked "No" automatically imply the design is not verified.
✓			Is the person performing the design verification qualified to originate the document?
✓			Is the design verification being performed by someone other than the supervisor of the originator?
✓			Were the design inputs correctly selected and incorporated into design?
✓			Are assumptions necessary to perform the design activity adequately described and reasonable? Where necessary, are assumptions identified for subsequent re-verifications when the detailed design activities are completed?
✓			Are the appropriate quality and quality assurance requirements specified?
✓			Are the applicable codes, standards and regulatory requirements including issue and addenda properly identified, and their requirements for design met?
		✓	Have applicable construction and operating experiences been considered?
✓			Have the design interface requirements been satisfied?
✓			Were appropriate design methods and computer programs used?
✓			Is the design output reasonable compared to design inputs?
		✓	Are the specified parts, equipment, and processes suitable for the required application?
		✓	Are the specified materials compatible with each other and the design environmental conditions to which the material will be exposed?
		✓	Have adequate maintenance features and requirements been specified?
		✓	Are accessibility and other design provisions adequate for performance of needed maintenance and repair?
		✓	Have adequate accessibility been provided to perform the in-service inspection expected to be required during the plant life?
		✓	Has the design properly considered radiation exposure to the public and plant personnel?
✓			Are the acceptance criteria incorporated in the design documents sufficient to allow verification that design requirements have been satisfactorily accomplished?
		✓	Have adequate pre-operational and subsequent periodic test requirements been appropriately specified?
		✓	Have adequate handling, storage, cleaning, and shipping requirements been specified?
		✓	Are adequate identification requirements specified?
		✓	Are requirements for record preparation review, acceptance, retention, etc., adequately specified?

Design Verifier: Allison Shumway Signature: Allison Shumway Date: 11/28/12

Approved by: J. Allan Tice Signature: J. Allan Tice Date: 11/29/12

S&C Review
David E. Nelson

11/30/12

PROJECT ANALYSIS AND CALCULATION RECORD

Title: ***Smooth vertical GMRS for the PSEG Site based on CEUS SSC***

Record No. 2047 -ACR- 080 (calcs)

Record No. 2047 -ACR- 081 (elec. files)

Rev.	Status	Date	Description	Prep. By	Rev. by	App.* by
0	FINAL	11/24/2012	Initial Issue	DAE	AMS	DAE

*Approval for release of results

Description of work:	Reviewer Initials
1. Are objectives clearly stated?	AMS
2. Are inputs correctly selected, stated, and referenced?	AMS
3. Are literature searches and background information completely described?	AMS
4. Are assumptions completely described and referenced?	N/A
5. Is an appropriate computer program used for analysis?	AMS
6. Are appropriate methods/equations used for hand calculations?	AMS
7. Are the results reasonable, considering the input?	AMS
8. Have mathematical checks been made to ensure the accuracy of the results?	AMS
9. Have the accuracy and conclusions been confirmed?	AMS

All calculations shall fully describe:

1. Objectives of analysis.
2. Design inputs, sources, and references.
3. Literature searches and background information.
4. Assumptions, basis for assumptions, and references.
5. If computer calculations, program name and version name.
6. If hand calculations, equations used and outputs.

1. Objectives of Analysis

Calculate smooth vertical ground-motion response spectra (GMRS) for the PSEG Site by applying V/H ratios to the horizontal GMRS calculated in Ref. 1.

2. Inputs

Horizontal GMRS from Ref. 1.

Vertical/Horizontal (V/H) ratios from Ref. 2 and 3.

Western US ground motion equations (Ref. 4, 5, and 6).

Deaggregation earthquake magnitude and distance parameters (Ref. 7).

V_{s30m} (mean shear wave velocity in the top 30 m) for the profile corresponding to the GMRS control elevation (-67 ft, NAVD) from Ref. 8.

10^{-4} and 10^{-5} median base rock PGA from Ref. 9.

3. Literature Search and Background Information

Recommended V/H ratios for response spectra are given in Ref. 2 and 3. There is no reference that directly recommends V/H ratios for CEUS soil sites, so multiple V/H ratios are derived here from various sources (including manipulating Western US (WUS) ground motion V/H ratios using Ref. 4, 5, and 6), and a conservative envelope is used to bound those estimates to derive a recommended set of V/H ratios for the PSEG Site.

Literature pertinent to this calculation as cited in the text and shown in the References listing at the end of this text was reviewed.

4. Assumptions and Basis

No assumptions were made that require later verification.

5. Computer Calculations

The only computer program used was Microsoft Excel 2010™. All electronic files for this calculation are included in Ref. 10.

6. Hand Calculations

All calculations are performed in the Excel spreadsheets PSEG_GMRS.xlsx, Campbell_Bozorgnia_2003.xlsx, and Gulerce_Abrahamson_2011.xlsx. These spreadsheets are contained in the electronic files for the calculation of smooth vertical GMRS for the PSEG Site (Ref. 10).

CALCULATION PROCEDURE:

The Excel spreadsheet PSEG_GMRS.xlsx contained in Ref. 10 calculates vertical GMRS at 38 frequencies for the PSEG Site.

1. Excel file PSEG_Horizontal_GMRS.xls is copied from Ref. 1 and renamed PSEG _GMRS.xlsx.

2. Worksheet *RG1.60_NUREG6728_VH_Ratios* in spreadsheet PSEG_GMRS.xlsx includes the V/H factors from Table 4-5 of Ref. 2 for CEUS rock conditions with PGA between 0.2-0.5g (NUREG/CR-6728 V/H ratios for CEUS rock). This worksheet also calculates V/H ratios from Reg. Guide 1.60 (Ref. 3). Recommended spectral amplitudes based on ground displacement for 0.25 Hz in Ref. 3 are converted to spectral accelerations as explained in notes in this worksheet.

3. Refs. 4 and 5 provide horizontal and vertical spectral acceleration attenuation models for different site conditions in shallow crustal active tectonic regions (e.g. WUS conditions). This model was implemented in worksheet *CB2003* of the spreadsheet Campbell_ Bozorgnia_2003.xlsx (Ref. 10). The input parameters are the earthquake magnitude, closest distance to seismogenic rupture, closest distance to the surface projection of fault rupture, fault dip, relative location of site and fault (i.e. if site is on the hanging wall side), and site class. The earthquake magnitude (M) and distance (R) values above are taken from the 10^{-4} and 10^{-5} HF deaggregations in Ref. 7 because the frequencies above 10 Hz are where the V/H ratio is highest, and it is important to represent this frequency range accurately. The amplitude of the GMRS is below that of the 10^{-5} UHRS, and the deaggregations at 10^{-4} and 10^{-5} are expected to bound the earthquakes that will control the GMRS. The background source zone corresponding to the M and R values was the Extended Continental Crust – Extended Margin which has a fault rupture mechanism that is predominantly strike-slip (Ref. 11) and a mean rupture dip of 90°. The site class is selected as firm rock, which corresponds to V_{s30m} value of 730 m/s computed in Ref. 8 for the profile corresponding to the GMRS control elevation (-67 ft, NAVD). The worksheet *CB2003* is copied twice and renamed *CB2003_1E-4HF* and *CB2003_1E-5HF* with the input parameters updated with the corresponding values for the 10^{-4} and 10^{-5} HF deaggregations, respectively.

   To validate the implementation of the model, the spreadsheet Campbell_ Bozorgnia_2003.xlsx also contains additional worksheets that compare model predictions using worksheet *CB2003* and published results in Ref. 4 and 5. V/H ratios will be computed by dividing frequency by frequency the vertical over the horizontal response spectral ordinates. These V/H ratios correspond to WUS conditions, which have peaks at frequencies of approximately 15 Hz and higher.

4. Ref. 6 provides a V/H ratio model for different site conditions in shallow crustal active tectonic regions (e.g. WUS conditions). This model was implemented in worksheet *GA2011* of the spreadsheet Gulerce_Abrahamson_2011.xlsx (Ref. 10). The input parameters are the earthquake magnitude, rupture distance, faulting mechanism, median PGA for V_{S30m} of 1,100 m/s (PGA_{1100}) and V_{S30m} at the site. The worksheet *GA2011* is copied twice and renamed *GA2011_1E-4HF* and *GA2011_1E-5HF* with the input parameters updated with the corresponding values for the 10^{-4} and 10^{-5} HF deaggregations, respectively.

The earthquake magnitude, rupture distance, and faulting mechanism are equivalent to the input parameters used in the previous step for Campbell and Bozorgnia (2003) implementation. The V_{s30m} for the profile corresponding to the GMRS control elevation (-67 ft, NAVD) is 730 m/s (Ref. 8).

The value of PGA_{1100} is not readily available from analyses performed to date. However, the 10^{-4} and 10^{-5} median base rock PGAs, which correspond to a shear wave velocity of 9200 fps (or 2804 m/s) are available from Ref. 9. Review of the V/H relation in Ref 6 indicates that for the GMRS profile (which has a V_{s30m} of 730 m/s), the PGA_{1100} value has no impact on the V/H ratios calculated at the lower frequencies. This is due to the fact that Ref. 9 authors recognized that V_{s30m} for rock sites is not a good predictor of site amplification at lower frequencies, and thus developed a period-dependent cutoff value for shear wave velocity. The V/H relation is not dependent on PGA_{1100} at the period dependent cutoff value for lower frequencies for the GMRS profile.

Furthermore, higher values of PGA_{1100} would be more conservative as they would result in higher V/H ratios. As a result, because the median PGA corresponding to the shear wave velocity of 2804 m/s from Ref. 9 would be higher than PGA_{1100} (due to the higher average shear wave velocity), a conservative approach is adopted whereby the median 10^{-4} and 10^{-5} base rock PGAs in Ref. 9 (0.125g and 0.511g, respectively) are used as a proxy for PGA_{1100}. To compare the impact of PGA_{1100}, Figure 1 presents the V/H ratios obtained for the 10^{-4} and 10^{-5} HF cases (from worksheets *GA2011_1E-4HF* and *GA2011_1E-5HF*, respectively) using the median 10^{-4} and 10^{-5} base rock PGA from Ref. 9 as a proxy for PGA_{1100} and compares them to the V/H ratios using a low PGA_{1100} of 0.05g. This comparison confirms the conservative nature of using higher PGA_{1100} on V/H at high frequencies and its lack of impact at lower frequencies (at and below 5Hz).

To validate the implementation of the model, the spreadsheet Gulerce_Abrahamson_2011.xlsx also contains additional worksheets that compare model predictions using worksheet *GA2011* and published results in Ref. 6. Most of the figures used to validate the implementation didn't report the PGA_{1100} value used to generate the figures. So, for the purpose of validating the model, PGA_{1100} values were selected to obtain a good match with the published results. All these PGA_{1100} values are reported in the spreadsheet Gulerce_Abrahamson_2011.xlsx (Ref. 10).

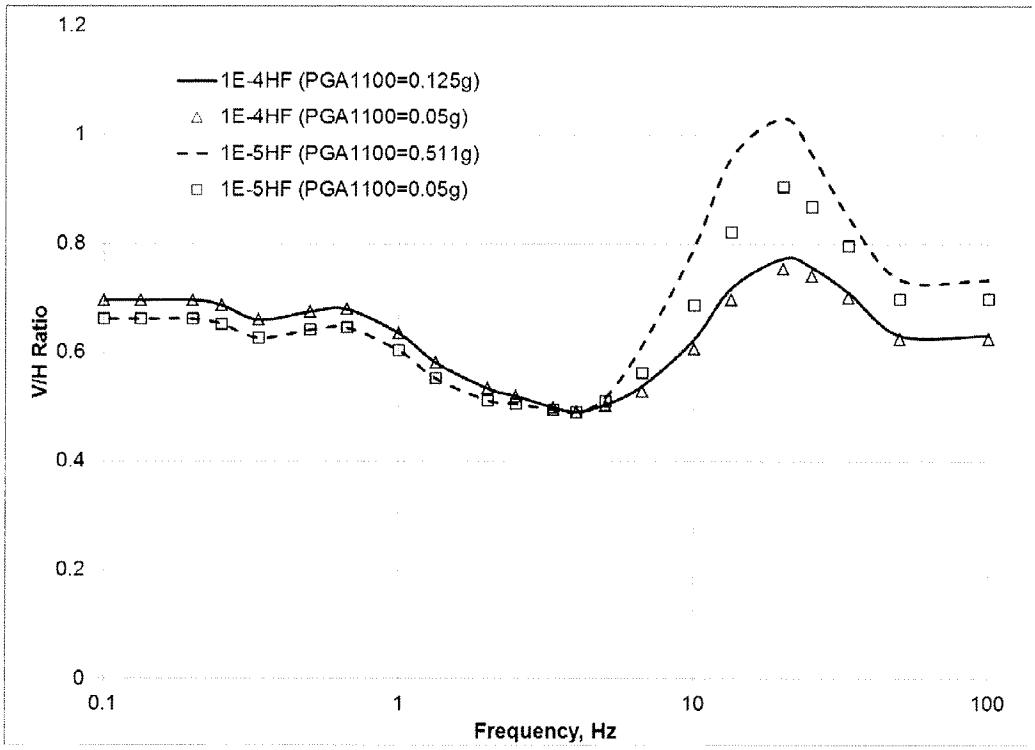

Figure 1. Comparison of 10^{-4} and 10^{-5} V/H ratios for different values of PGA_{1100}. These V/H ratios correspond to WUS conditions.

Source: Chart *GA_VH_comp* in Excel file Gulerce_Abrahamson_2011.xlsx *(Ref. 10).*

5. The WUS V/H relations based on Ref. 4, 5, and 6 (steps 3 and 4 above) are copied into worksheet *WUS_GMPEs_VH* in Excel file PSEG_GMRS.xlsx (Ref. 10). The CEUS rock spectrum developed from Ref. 2 (shown in Figure 2), demonstrated that V/H ratios in the CEUS have peaks at high frequencies (40 Hz and higher) as opposed to the V/H ratios in the WUS that tend to have peaks at frequencies of approximately 15 Hz and higher. As a result, in order to transform the WUS V/H ratios from steps 3 and 4 to CEUS V/H ratios, the frequency axis is scaled by a factor of 3 to approximate the difference between CEUS and WUS ground motion frequencies (as shown in Figure 2). The recommended V/H ratios are input in worksheet *Recommended_VH* (shown in Figure 2) and envelop all the V/H ratios developed or derived for the CEUS with the exception of Reg. Guide 1.60 ratios (Ref. 3), which are considered obsolete because they are based on ground motion records obtained primarily in California and all prior to 1973. Figure 2 presents all of the V/H ratios developed for the PSEG Site, including the recommended V/H ratio. The 'unshifted' V/H ratios based on WUS conditions generated based on Ref. 4, 5, and 6 (steps 3 and 4 above) are also shown as dashed light lines for comparison only. The 'unshifted' WUS V/H ratios are not all bounded (e.g. Campbell and Bozorgnia 1E-5 HF unshifted) as they only represent WUS conditions, which are not applicable here. Only the 'shifted' V/H ratios are bounded.

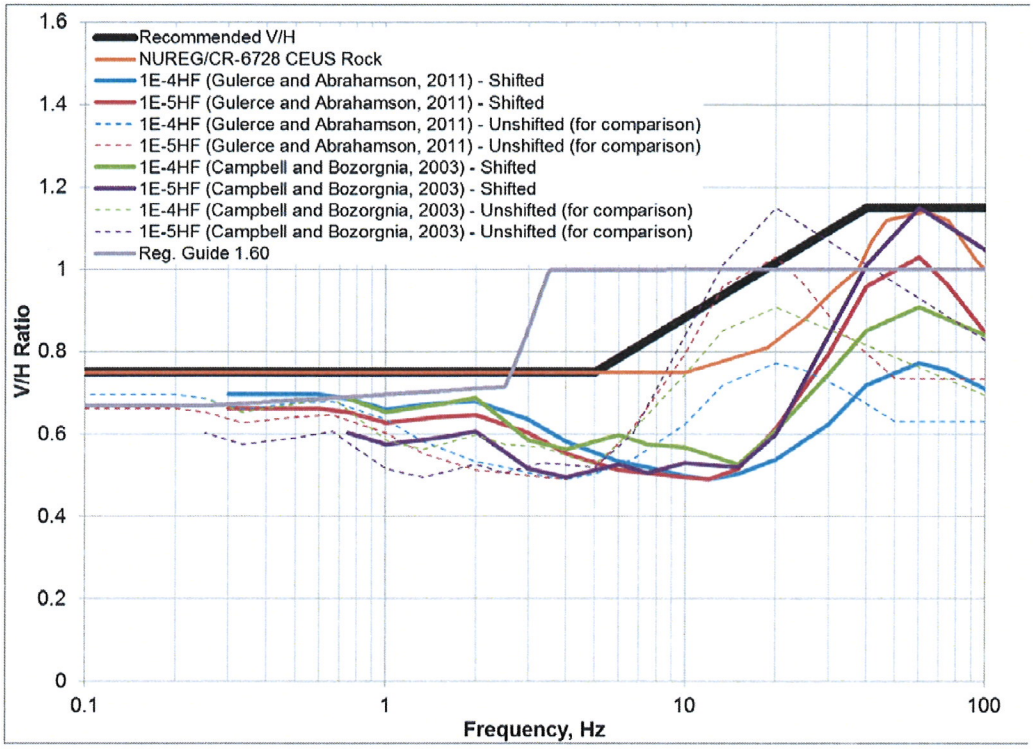

Figure 2. V/H ratios calculated by various methods.

Source: Chart *VH_Ratio* in Excel file PSEG_GMRS.xlsx *(Ref. 10).*

6. The final vertical GMRS is calculated in column J on sheet *GMRS_Smoothed* in file PSEG_GMRS.xlsx by multiplying the final smoothed horizontal GMRS (Ref. 1) by the corresponding recommended V/H ratio at each corresponding spectral frequency (column I). The final vertical GMRS spectral accelerations for the PSEG Site for 38 frequencies are located in cells N6:N43 with the corresponding frequencies in cells L6:L43.

SUMMARY OF RESULTS:

Figure 3 is a plot of the final horizontal and vertical GMRS for the PSEG Site (for 335 spectral frequencies between PGA (100 Hz) and 0.1 Hz). Table 1 shows numerical values for the final GMRS spectrum for the PSEG Site (for 38 spectral frequencies).

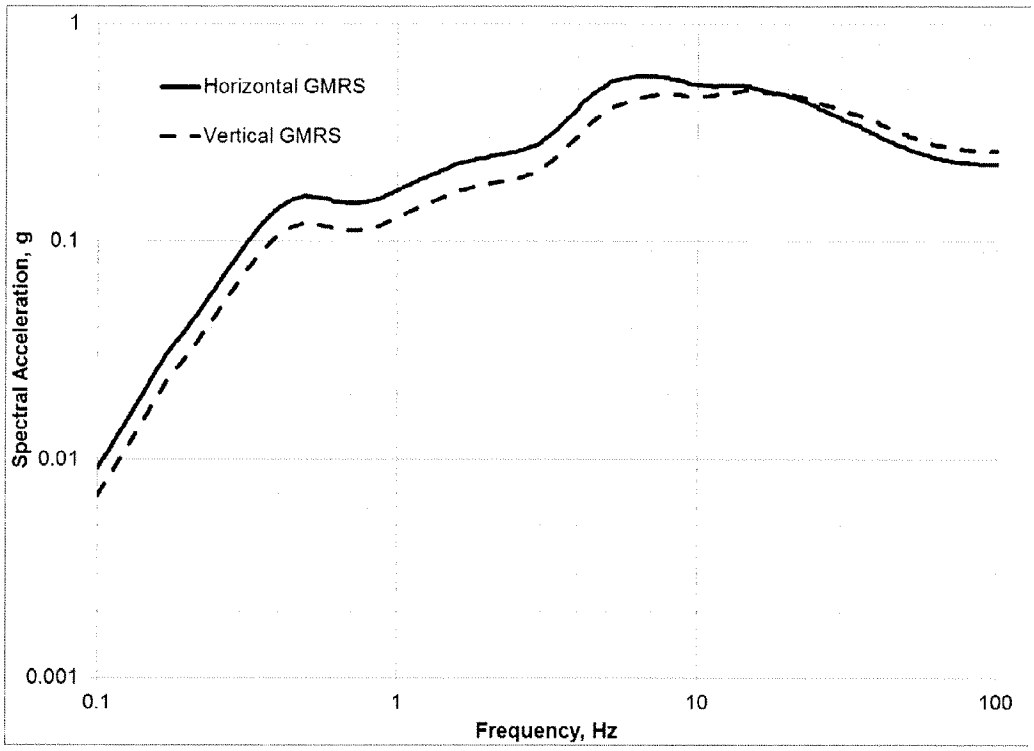

Figure 3. Final smoothed horizontal and vertical GMRS for the PSEG Site.

Source: Chart *Final_GMRS* in Excel file PSEG_GMRS.xlsx (Ref. 10).

Table 2. Amplitudes for the Horizontal and Vertical GMRS for the PSEG Site

Frequency (Hz)	Horizontal GMRS (g)	Vertical GMRS (g)
0.1	9.14E-03	6.86E-03
0.125	1.49E-02	1.12E-02
0.15	2.28E-02	1.71E-02
0.2	4.04E-02	3.03E-02
0.3	8.98E-02	6.74E-02
0.4	1.42E-01	1.07E-01
0.5	1.60E-01	1.20E-01
0.6	1.54E-01	1.16E-01
0.7	1.50E-01	1.12E-01
0.8	1.53E-01	1.15E-01
0.9	1.60E-01	1.20E-01
1	1.72E-01	1.29E-01
1.25	1.97E-01	1.48E-01
1.5	2.20E-01	1.65E-01
2	2.45E-01	1.84E-01
2.5	2.59E-01	1.94E-01
3	2.84E-01	2.13E-01
4	4.17E-01	3.13E-01
5	5.26E-01	3.95E-01
6	5.67E-01	4.45E-01
7	5.72E-01	4.66E-01
8	5.59E-01	4.70E-01
9	5.39E-01	4.65E-01
10	5.23E-01	4.62E-01
12.5	5.17E-01	4.79E-01
15	5.11E-01	4.91E-01
20	4.63E-01	4.71E-01
25	4.13E-01	4.37E-01
30	3.66E-01	4.01E-01
35	3.32E-01	3.73E-01
40	3.02E-01	3.47E-01
45	2.81E-01	3.23E-01
50	2.67E-01	3.07E-01
60	2.45E-01	2.81E-01
70	2.33E-01	2.68E-01
80	2.28E-01	2.62E-01
90	2.26E-01	2.60E-01
100	2.25E-01	2.59E-01

References

1. AMEC (2012). *Smooth horizontal GMRS for the PSEG Site*, AMEC Calc Analysis No. 0360-RAI-061-8 Rev 0.
2. Risk Engineering, Inc. (2001). Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-Consistent Ground Motion Spectra Guidelines, US Nuc. Reg. Comm. Rept. NUREG/CR-6728.
3. US Atomic Energy Comm (1973). Regulatory Guide 1.60 Design Response Spectra for Seismic Design of Nuclear Power Plants, Wash. DC, Dec.
4. Campbell, K.W. and Bozorgnia, Y.M. (2003). *Updated near-source ground motion (attenuation) relations for the horizontal and vertical components of peak ground acceleration and acceleration response spectra*, Bulletin of Seismological Society of America, 93(1), pp. 314-331.
5. Bozorgnia, Y.M., and Campbell, K.W. (2004), *The vertical-to-horizontal response spectral ratio and tentative procedures for developing simplified V/H and vertical design spectra*, Journal of Earthquake Engineering, 8, pp. 175-207.
6. Gülerce, Z., and Abrahamson, N.A. (2011). *Site-specific Design Spectra for Vertical Ground Motion*, Earthquake Spectra, Vol. 27, No. 4, pp. 1023-1047.
7. AMEC (2012). *Deaggregation of 10^{-4}, 10^{-5} and 10^{-6} base rock hazard (no CAV) for the PSEG site,* AMEC Calc/Analysis No. 0360-RAI-061-3 Rev 0.
8. AMEC (2012). *Artificial shear-wave velocity profiles for updated PSEG site response calculations under CEUS SSC*, AMEC Calc/Analysis No. 0360-RAI-061-5 Rev 0.
9. AMEC (2012). *Base rock hazard calculation (no CAV) for the PSEG Site*, AMEC Calc/Analysis No. 0360-RAI-061-2 Rev 0.
10. AMEC (2012). *Smooth vertical GMRS for the PSEG Site based on CEUS SSC*, AMEC Calc/Analysis No. 0360-RAI-061-9 Rev 0 Supplement (2047-ACR-081), Electronic Files.
11. USNRC (2012). Technical Report: *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities*. U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington DC, NUREG-2115.

CALCULATION 0360-RAI-061-9 - SUPPLEMENTAL ELECTRONIC FILES FOR VERTICAL GMRS FOR THE PSEG SITE

Contained in zip file titled "Calc 0360-RAI-061-9 Rev. 0 SUPPLEMENT (2047-ACR-081)"
No paper printout